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APPLICATION FOR U.S. LETTERS PATENT

Title:

HIGH K DIELECTRIC MATERIAL AND
METHOD OF MAKING A HIGH K DIELECTRIC MATERIAL

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HIGH K DIELECTRIC MATERIAL AND METHOD OF MAKING A HIGH K DIELECTRIC MATERIAL

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

The invention relates to semiconductor devices and components and, specifically, to metal oxide dielectric materials for use in semiconductor devices and components.

[0002] 2. Description of Related Art

[0003] Silicon dioxide (SiO_2) is widely employed in the semiconductor industry as a gate dielectric for both logic and memory applications. When SiO_2 , which has a dielectric constant (K) value of approximately 4, is employed in a thin (i.e., less than about 15 Å) layer, the amount of leakage current from the gate dielectric can become prohibitively high.

[0004] To reduce leakage current, SiO_2 has been substituted with a high K dielectric material, i.e., a material with a K value of greater than 4. Most of these high K gate dielectrics are metal oxides. For example, U.S. Patent No. 6,184,072 describes using metals like zirconium and hafnium to increase the dielectric value of an SiO_2 gate dielectric layer. Most metal oxides, however, have a large number of structural defects. Problems associated with the use of metal oxides having these structural defects include high interface

state densities between the oxide and the underlying semiconductor. These charges can provide a conduction path in the dielectric layer, which leads to adverse device performance. That is, these defects may generate a conduction path in the dielectric, and may also generate charges in the dielectric and at the dielectric/Si interface. The presence of these charges (fixed charges) in the dielectric affects the threshold voltage of a transistor having a metal oxide gate dielectric, and more importantly, the carrier mobility at the dielectric/Si interface.

BRIEF SUMMARY OF THE INVENTION

[0005] The present invention is directed to solving the above-described problems associated with using a metal oxide to provide a high K dielectric material. More specifically, the invention addresses problems associated with the use of Group III metal oxides as a high K dielectric material.

[0006] The present invention provides a high K dielectric material layer with a reduced number of structural defects and with a decreased fixed charge density by incorporating a Group V element in a Group III metal oxide material. Specifically, the incorporation of a Group V element in a Group III metal oxide reduces the number of defects in the dielectric material, and reduces both the fixed charge density and the conduction current of the dielectric material. The dielectric material has particular use wherever a dielectric is used in semiconductor structures, for example, as a gate dielectric for a transistor, or as a capacitor dielectric.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] These and other features and advantages of the present invention will become more fully apparent from the following detailed description of the exemplary embodiments of the invention which are provided in connection with the accompanying drawings.

[0008] FIG. 1 is a partial cross-sectional view of a dielectric layer constructed in accordance with the present invention for use with a semiconductor device.

[0009] FIG. 2 is a graph of capacitance versus gate voltage for a dielectric layer deposited in an oxygen atmosphere, and for dielectric layers deposited in an atmosphere containing a mixture of oxygen and various amounts of nitrogen.

DETAILED DESCRIPTION OF THE INVENTION

[0010] FIG. 1 is a partial cross-sectional view of a layered structure 110 having a high K metal oxide dielectric layer 130 according to the present invention on a substrate 120. Substrate 120 is typically silicon. The layered semiconductor structure 110 may be employed as an element of an electronic component such as integrated circuit devices and integrated or discrete components having a layer of dielectric material. For example, high K metal oxide dielectric layer 130 may be employed as a gate dielectric layer in an electronic component comprising a transistor. The electronic component could

comprise a capacitor, with the dielectric material forming a dielectric layer between conductive layers of the capacitor.

[0011] As described above in the Description of Related Art, conventional high K Group III metal oxides typically have a relatively high charge in the bulk of the film and at the dielectric-semiconductor interface. For the reasons described below, however, the high K metal oxide layer 130 according to the present invention has a reduced charge, i.e., typically a fixed charge density of less than $2 \times 10^{11}/\text{cm}^2$. The term “fixed charge density” as used herein means an effective charge measured at the semiconductor dielectric interface, and also accounts for the interface state density.

[0012] The metal oxide layer 130 includes a Group III metal oxide, such as, for example, aluminum oxide (Al_2O_3). To provide a metal oxide layer 130 having a reduced fixed charge density, the metal oxide layer 130 incorporates a Group V element, such as, for example, nitrogen. More specifically, in one embodiment of the method of incorporating the Group V element in the Group III metal oxide, the metal oxide layer 130 is deposited in an atmosphere containing a mixture of oxygen and nitrogen. The deposition in the presence of an oxygen-nitrogen mixture provides a metal oxide layer 130 having a reduced fixed charge density. The oxygen-to-nitrogen ratio of the oxygen-nitrogen deposition mixture may range, for example, from 24:6, to 18:12, to 9:21 (see Table 1 below), depending upon the characteristics desired in the resultant metal oxide layer 130.

[0013] Although the applicants do not wish to be held to a particular theory, the applicants believe that the incorporation of the Group V element facilitates electronic bonding of the Group III oxides and thereby reduces the fixed charge density. More specifically, it is believed, for example, that addition of nitrogen during the growth of the metal oxide may convert the oxide to metal oxynitride.

[0014] EXAMPLE

[0015] Using a Varian M2000 metal sputtering tool, various dielectric layers each having an approximate thickness of 10 nm were deposited. FIG. 2 is a graph of capacitance versus gate voltage for a dielectric layer deposited in an oxygen atmosphere, and dielectric layers deposited in an atmosphere containing oxygen and various amounts of nitrogen. An aluminum oxide (i.e., a Group III oxide) layer was reactive-sputter deposited in an oxygen-only atmosphere (i.e., deposited according to a conventional technique). The line labeled "30:0" in FIG. 2 represents the performance of the aluminum oxide layer reactive-sputter deposited in the oxygen-only atmosphere. To provide a metal oxide layer 130 which also includes the Group V element nitrogen, the sputtering was done in a mixture of oxygen and nitrogen. The addition of nitrogen to the oxygen atmosphere reduced the fixed charge density. For example, oxygen-to-nitrogen deposition ratios of 24:6, 18:12, and 9:21 all provide a dielectric layer having a lower fixed charge density than a dielectric layer deposited in an oxygen-only atmosphere. Table 1 summarizes the fixed charge density associated with each of the dielectric layers.

[0016] Table 1

O/N Ratio	Fixed Charge Density/cm ²
30:0	-4.5 x 10 ¹²
24:6	-7.5 x 10 ¹¹
18:12	+3.0 x 10 ¹⁰
9:21	+9.0 x 10 ¹¹

[0017] Though the use of reactive sputtering is described in the Example as the method of incorporating nitrogen in the metal oxide, the nitrogen may be incorporated by various other methods, such as, for example, annealing of the metal oxide film in the presence of N₂O, NO, or NH₃; atomic layer deposition (ALD), chemical vapor deposition (CVD), and metalorganic chemical vapor deposition (MOCVD) using N₂O, NO, or NH₃; plasma nitridation; and oxidation of metal nitrides.

[0018] Furthermore, although the invention has been exemplified as employing an oxygen-nitrogen deposition mixture to reduce the fixed charge density in an aluminum oxide, the invention is not limited to the nitrogen and aluminum oxide embodiments. Rather, the invention can be employed to reduce the fixed charge density in Group III metal oxides other than aluminum oxide, such as, for example, yttrium oxide (Y₂O₃). In addition, the deposition mixture may include a Group V element other than nitrogen, such as, for example, phosphorous. The invention can also be employed to

reduce the fixed charge density in multi-component oxides that include a Group III metal, such as, for example, a Zr-Al-O oxide.

[0019] Accordingly, the above description and accompanying drawings are only illustrative of exemplary embodiments that can achieve the features and advantages of the present invention. It is not intended that the invention be limited to the embodiments shown and described in detail herein. The invention is limited only by the scope of the following claims.